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Design optimization of Flameless-Oxyfuel soaking pit furnace using CFD technique

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Abstract

The effect of the combustion chamber's configuration on the characteristics of flow and combustion parameters has been numerically investigated for a multi injecting, LPG, Flameless Oxy-fuel burner in a real-size soaking pit furnace, using CFD simulation. The simulation has been performed on two different furnace configurations, namely; small and large chambers of 15 m^3 and 27 m^3, with a height to width ratios of 1.49 and 2.02 respectively and with corresponding burner capacities of 560 kW and 900 kW. A major experimental trial has been performed in order to validate the results and reasonable consistency has been observed. The predicted results, with particular focus on the temperature distribution and heat transfer rate of two cases have been studied in detail.

Flameless-oxyfuel;soaking pit furnace; heat transfer

1. Introduction

Condition of soaking process, including the uniformity of temperature profile and heat transfer rate plays an essential role in the total energy consumption, final quality of soaking process and pollution production in the chain [2]. Simulation of industrial combustion systems involving multiple burners using CFD modelling is still a challenging problem. Integrating burners with jet scales in order of a few inches within a large domain in order of 10 to 1000meter is still a complex problem [5]. Increment of demanding rate for high quality steel in higher volume together with recent energy and pollution crisis brings up the necessity of a constant effort for development of existing facilities and optimizations. Regarding this new technology of Flameless-oxyfuel combustion has been introduced in 90s. In this study, the effect of the combustion chamber's configuration on the characteristics of flow and combustion parameters has been investigated for a multi injecting, LPG in a real-size soaking pit furnace, using CFD simulation.

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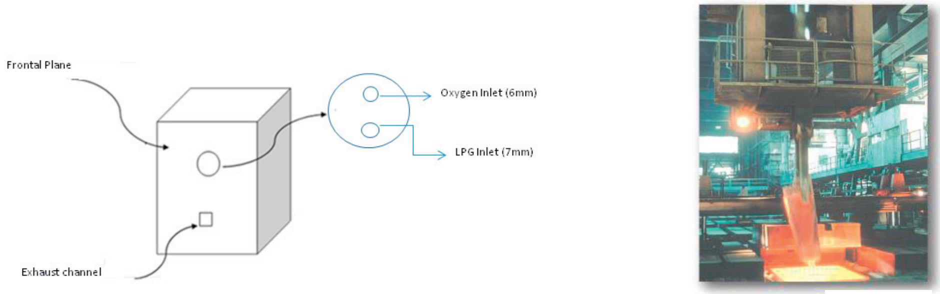
Simulations have been performed on two different furnace configurations, namely; small and large chambers of 15 m^3 and 27 m^3, with height to width ratios of 1.49 and 2.02 and burner capacities of 560kW and 900kW respectively.

2. Material and Methods

2.1 Soaking Pit Furnace

The furnace structure is as a rectangular prism with a cross section of 2838×1885 mm^2, with injecting system and exhaust on the frontal wall (Figure 1). The burner is located in 800mm lower than the lid of the chamber and contains two nozzles for separate injection of fuel and oxygen.



(a) (b)

Fig. 1. Soaking pit furnace (a). Schematic structure of the furnace (b).Loading furnace

Ingots are in a cone shape, top area of 360,000 mm^2 and bottom surface area of 84,100 mm^2. In large scale the furnace height is increased by 1500mm and cell width is increased by 250 mm and Length by 100 mm. The corresponding burner capacity is considered to be 900kW.The feeding parameters of two cases are listed in table 1. The Standard K-ε flow model, Discrete Ordinates (DO) method for radiation model and PDF (probability density function) combustion model have been chosen for enrolling the simulation.

Table 1. Boundary Condition for Inlet flow of pilot case

Parameter	Small Scale Chamber	Large Scale Chamber	Unit
Oxygen Inlet Mass Flow	0.04	0.06	Kg/s
Oxygen injection Velocity	474	507	m/s
Propane Inlet Mass Flow	0.012	0.02	Kg/s
Propane injection Velocity	161	242	m/s

2.2 Verification and Validation

In here major experimental trial has been run on the pilot case of study; one permanent-immobile thermocouple acts as "reference thermocouple" while the temperature of combustion products has been measured in 8 points inside the chamber after the heating process. The position of inserting thermocouples has been chosen in two different levels in height of 2015mm and 1015mm. In this trial probe region of the thermocouples are covered by a cone shape protecting layer, in order to eliminate the effect of radiation on sensed temperature. [8]

3. Results and Discussion

3.1. Experimental Results and Validation

Figure 2 illustrates the incontinency between measured temperatures and predicted results.The lowest value of inconsistency, seen in the middle region of the chamber, stated almost 1%, and The highest amount of inconsistency is observed in the rear region of the chamber where the bulk of hot flue gases encounter the rear wall (8%) .The measured values in the other parts of the chamber shows a perfect agreement (less than 6%) with simulation results and in a general view a comprehensive accordance among the rate of temperature distribution is observed between values which indicates the validity of the predicted results.

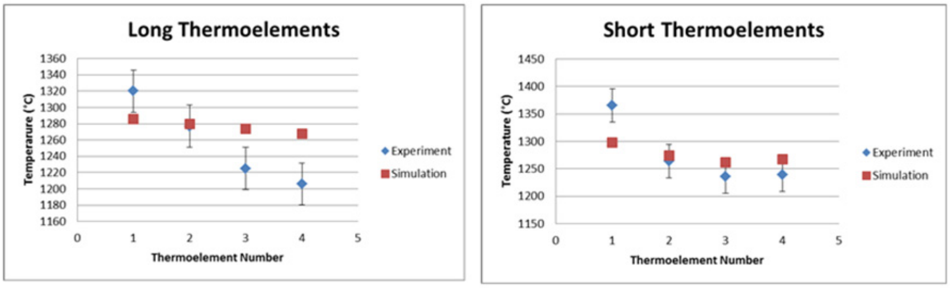


Fig. 2. Inconsistency between Experiment and Simulation results (a) Long Thermocouples; (b) Short Thermocouples

3.2 Simulation Results

3.2.1 Temperature Profile

Figure 3 shows the temperature profile of two studied cases, range of 800$^{°C}$ and 1500$^{°C}$.Enlargement procedure will create the possibility of developing a better 'flameless oxyfuel' combustion. This method highly modifies the non-uniformity of temperature distribution in oxyfuel combustions, caused by high localized flame temperature [4].In the new configuration of furnace and ingot arrangement, ingots derive a benefit from being in a more temperature homogeneous region regarding the fact that the flame flow has a distance of almost 1100 mm from the top of the ingots.

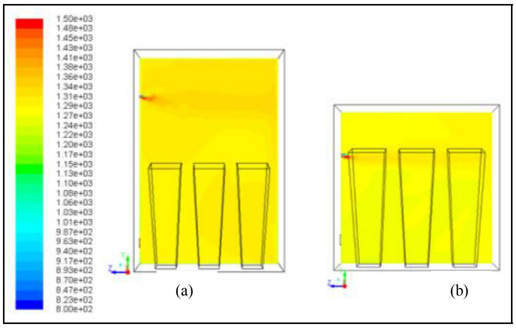


Fig.3. Temperature distribution profile on the middle plane of the chamber (a) Large scale chamber; (b) Small scale chamber

Chart 1 briefly shows difference of exposed temperature around ingots' surface in two cases of study; the maximum and minimum temperature in small chamber have a larger diversity and total temperature gradient is 100 °C more in this design compare to the bigger chamber.

3.2.1 *Heat Transfer*

In average approximately 80% of the heat transfer in soaking pit furnace is performed by radiation and rest by convection [2]. The maximum incident radiation is happening in the rear part of the chamber which is due to the localized

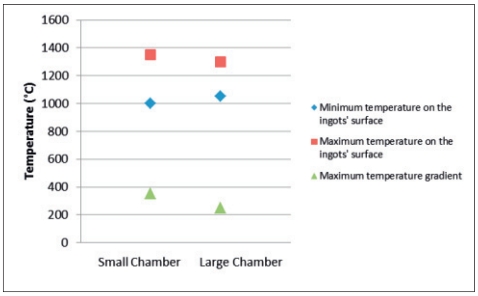


Chart. 1. Comparison of Temperature difference in two cases

hot bulk of flue gas eddies in that area and the two opposite side of developed boundary layer close to the wall. This amount is considerably higher in small scale chamber, which is due to closer distance between peak temperature flue gas and incident surface, in contrast with large scale chamber. This will negatively affect the efficiency of heat transfer in the latter case, while will help with achieving a more uniformity. The maximum difference in incident radiation on the ingots' surfaces in large and small scale is 350W /m^2 and 600 W/m^2 respectively.

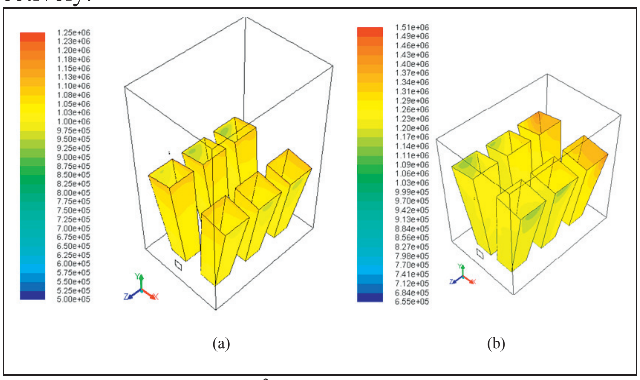


Fig. 4 Incident radiation on the ingots' surface (W/m^2) (a) Large scale chamber; (b) Small scale chamber Heat Transfer

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Biography

Mersedeh Ghadamgahi is a R&D engineer, employed by Ovako group in Hofors, Sweden, which is also working on her PhD at KTH, Royal Institute of Technology in Stockholm, Sweden in the department of Energy and Furnace Technology. Her thesis is about optimizing and updating soaking pit furnaces in the steel production route, a concern of both academy and industry